FIG. 1

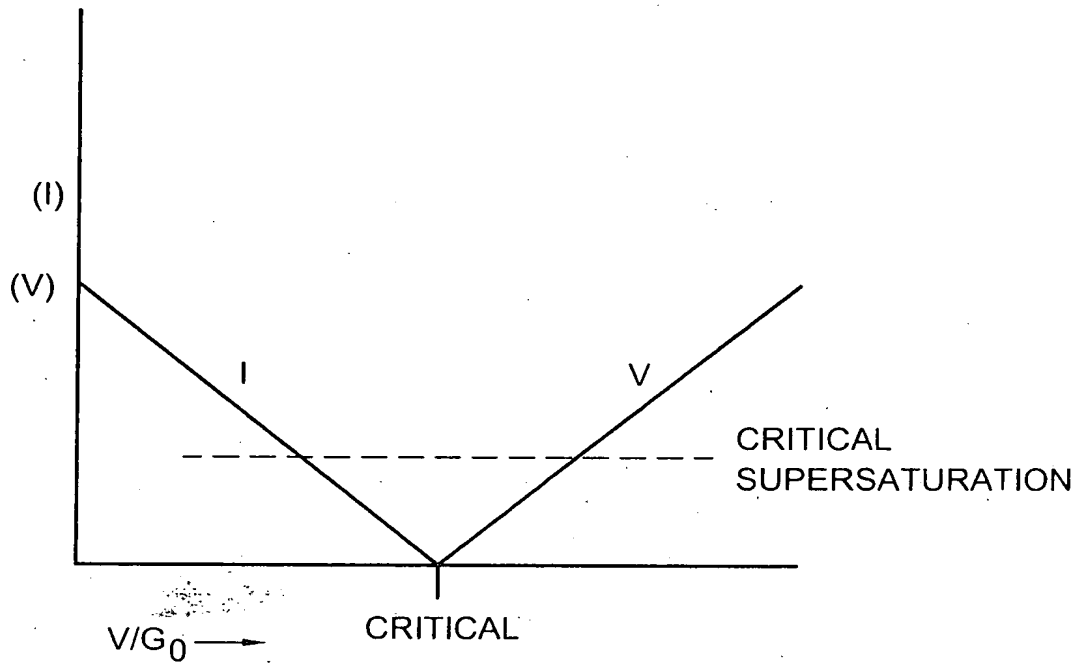

(I)
(V)
I
V
CRITICAL
SUPERSATURATION
V/G0
CRITICAL

FIG. 2

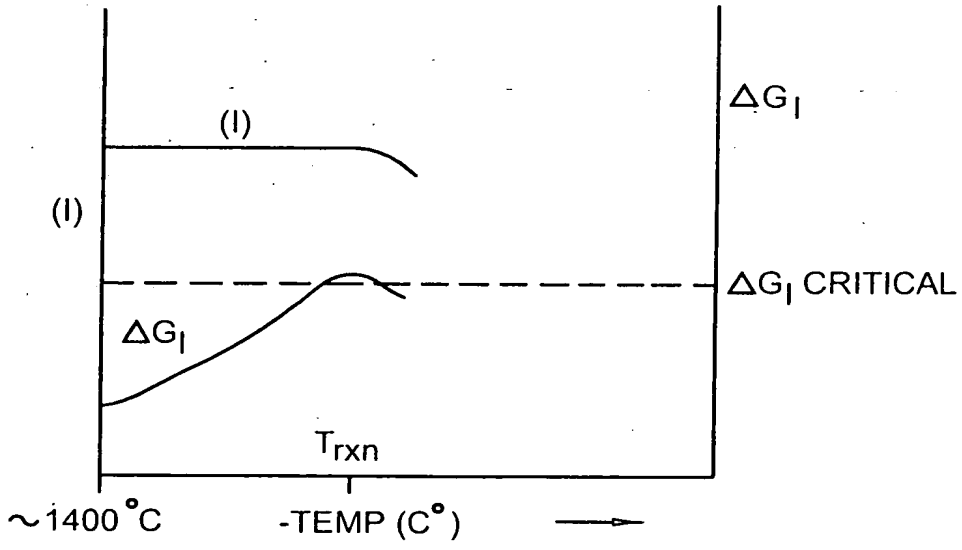

(I)
(I)
ΔGI
ΔGI CRITICAL
ΔGI
Trxn
~1400 °C
-TEMP (C°)

FIG.3

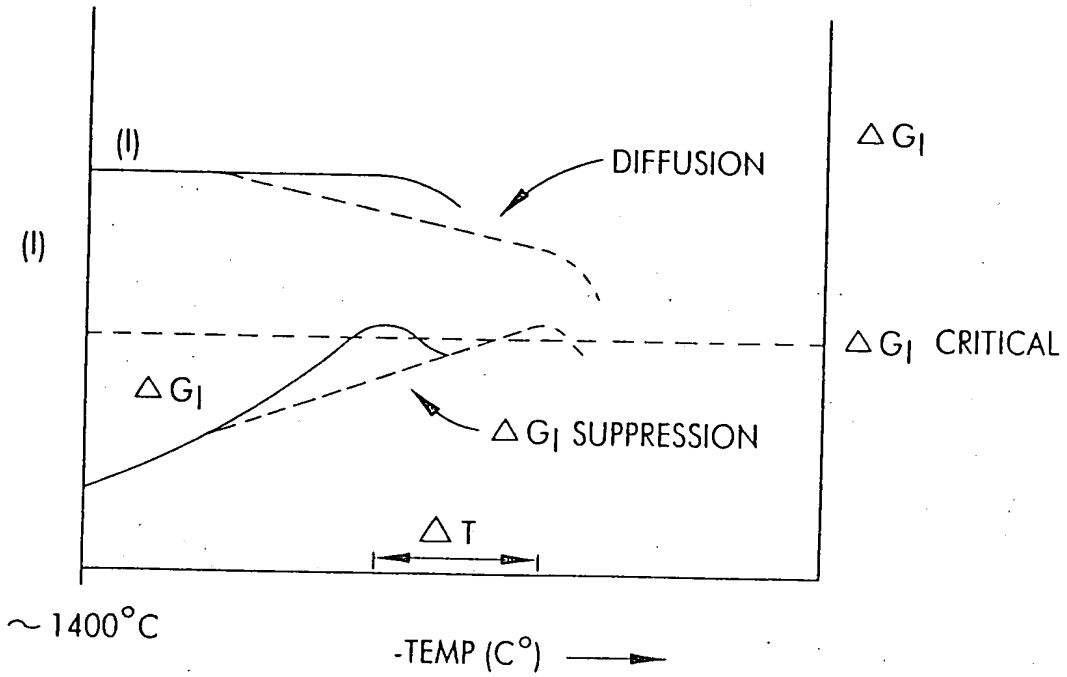

(I)
(I)
DIFFUSION
ΔG
ΔG CRITICAL
ΔG
ΔG SUPPRESSION
ΔT
~1400°C
-TEMP (C°)

FIG.4

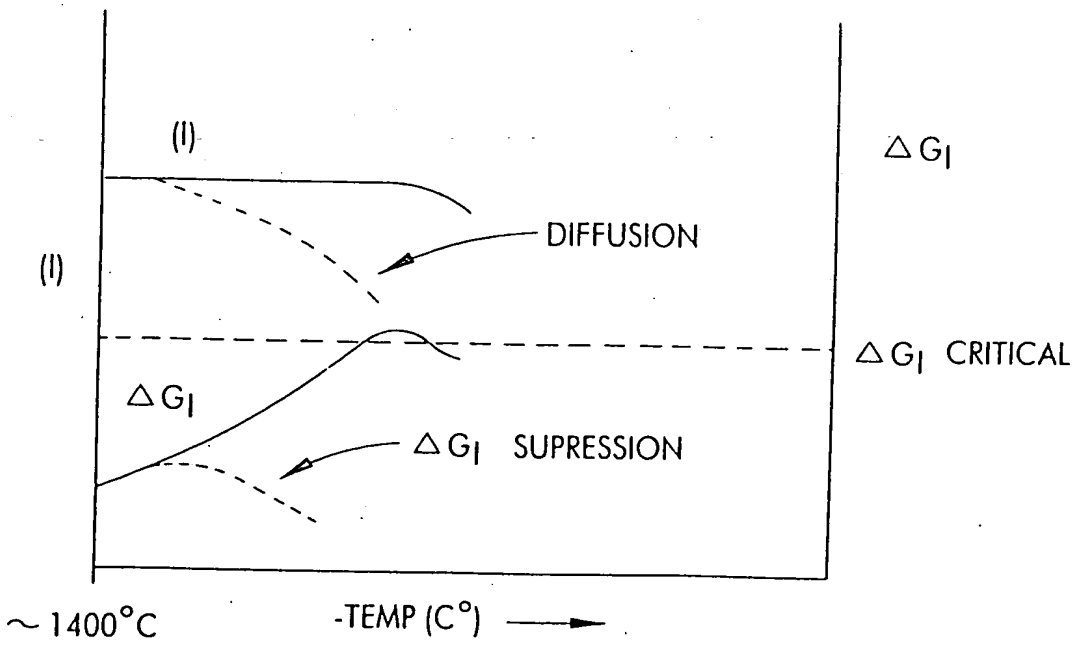

(I)
(I)
DIFFUSION
ΔG
ΔG CRITICAL
ΔG
ΔG SUPRESSION
~1400°C
-TEMP (C°)

FIG. 5

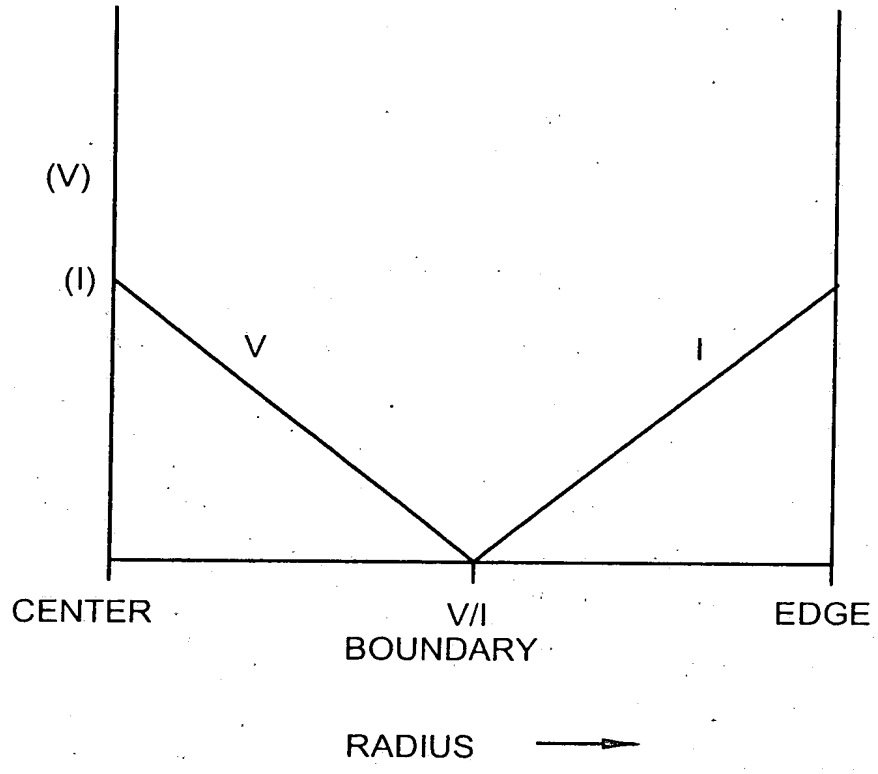

(V)
(I)
V
I
CENTER
V/I
BOUNDARY
EDGE
RADIUS

FIG. 6

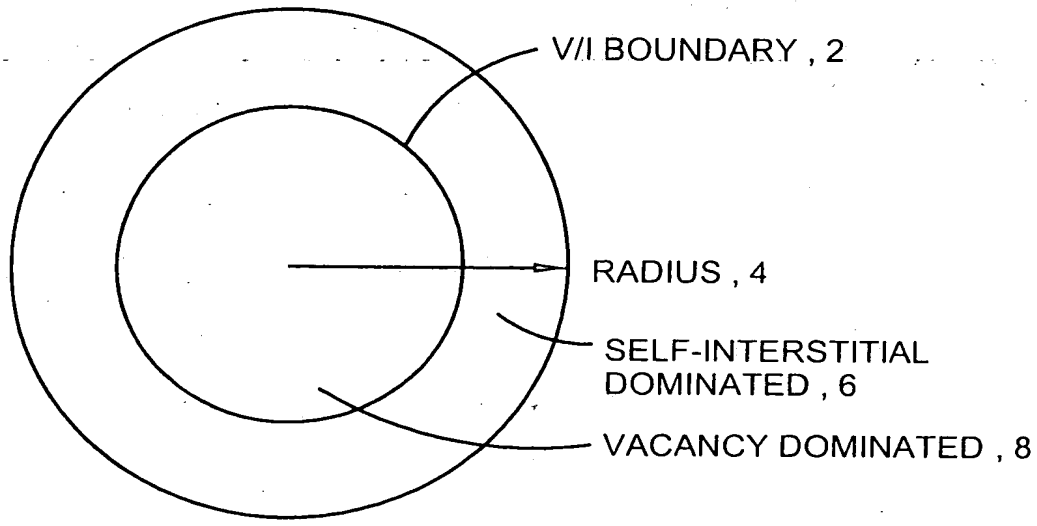

V/I BOUNDARY , 2
RADIUS , 4
SELF-INTERSTITIAL
DOMINATED , 6
VACANCY DOMINATED , 8

FIG.7A

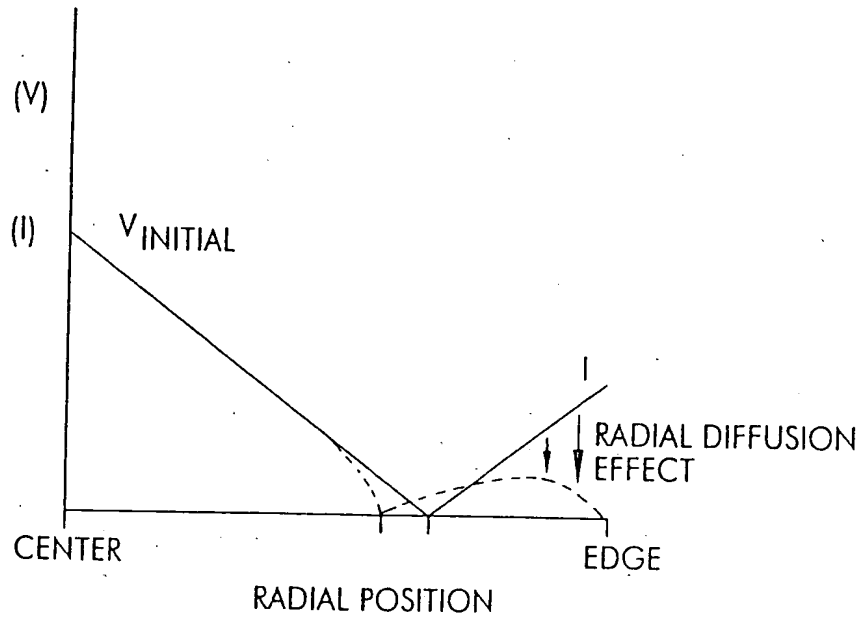

(V)
(I)
$V_{INITIAL}$
I
RADIAL DIFFUSION EFFECT
CENTER
EDGE
RADIAL POSITION

FIG.7B

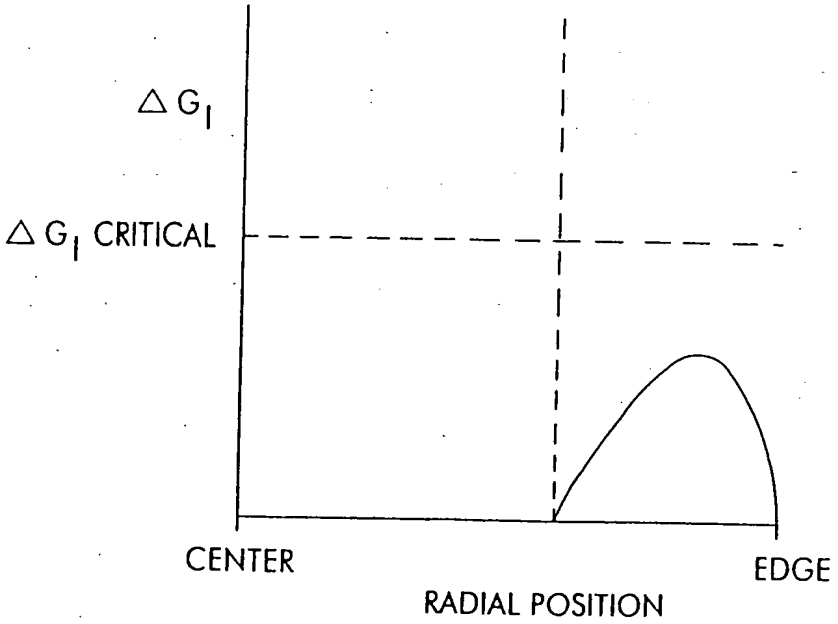

$\triangle G_I$
$\triangle G_I$ CRITICAL
CENTER
EDGE
RADIAL POSITION

FIG.7C

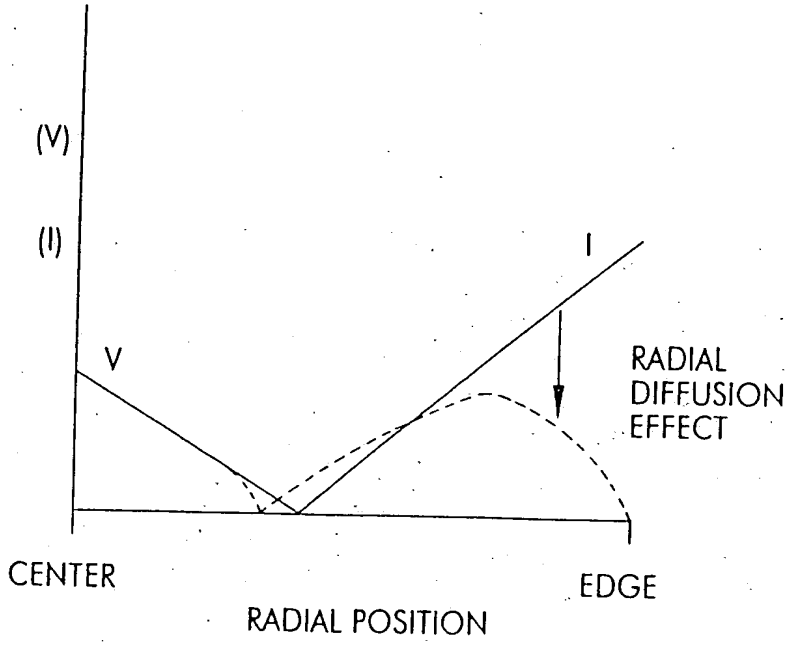

(V)
(I)
V
I
RADIAL
DIFFUSION
EFFECT
CENTER
EDGE
RADIAL POSITION

FIG.7D

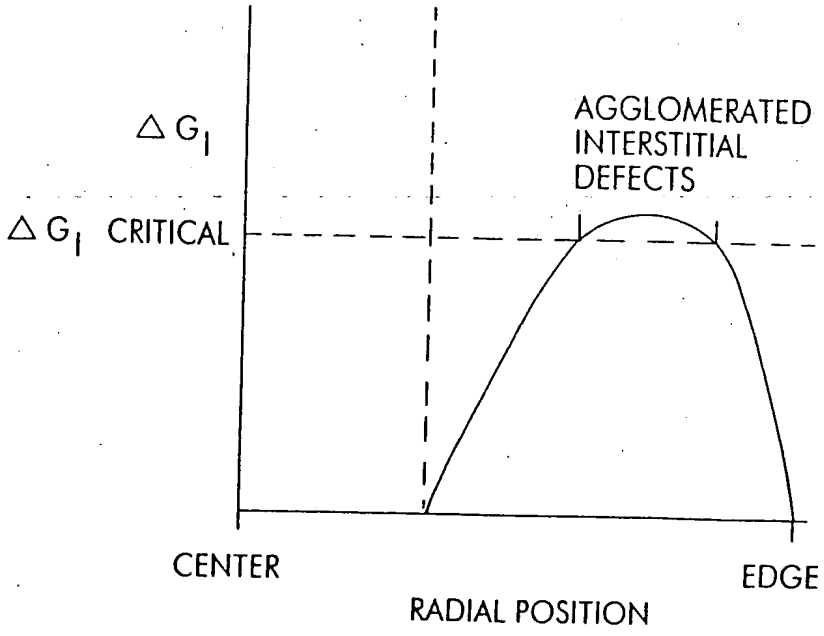

ΔG_I
ΔG_I CRITICAL
AGGLOMERATED
INTERSTITIAL
DEFECTS
CENTER
EDGE
RADIAL POSITION

FIG.7E

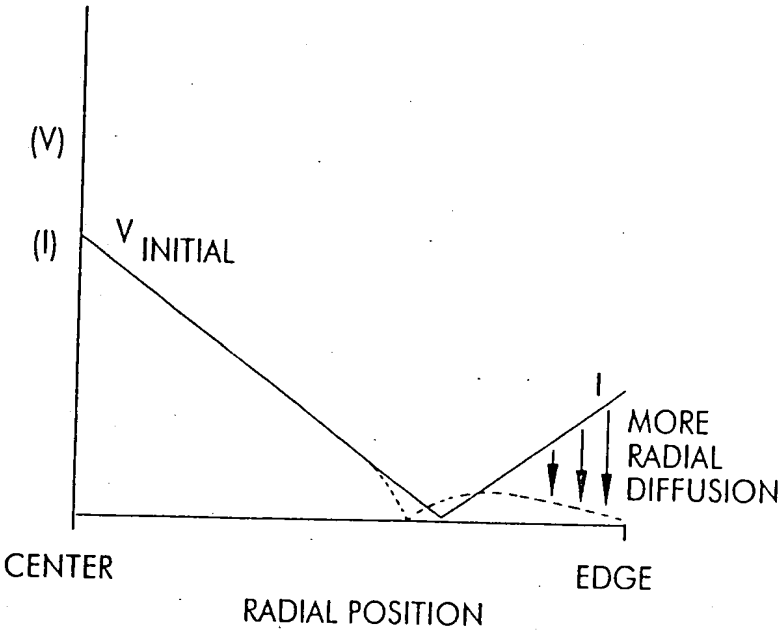

(V)
(I)
V INITIAL
I
MORE
RADIAL
DIFFUSION
CENTER
EDGE
RADIAL POSITION

FIG.7F

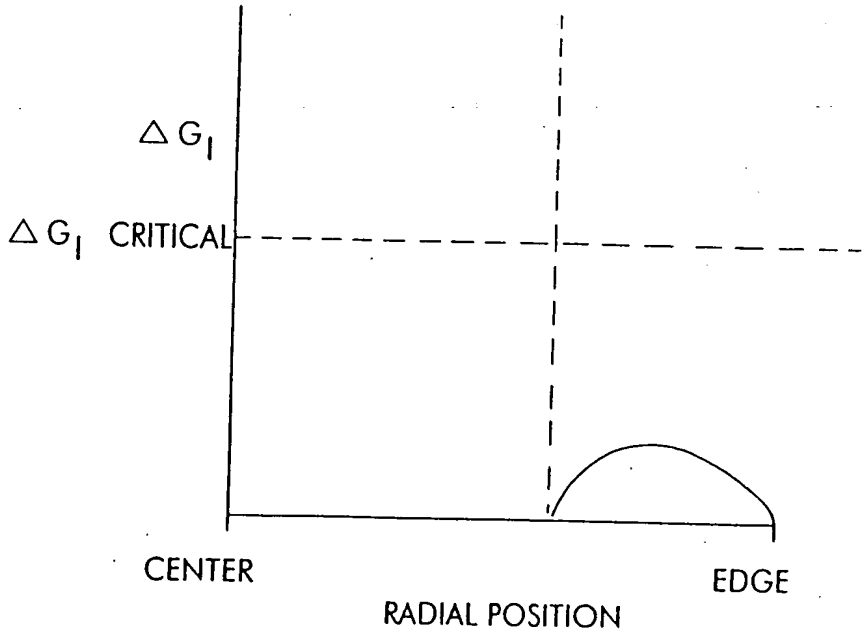

△ G1
△ G1 CRITICAL
CENTER
EDGE
RADIAL POSITION

FIG.7G

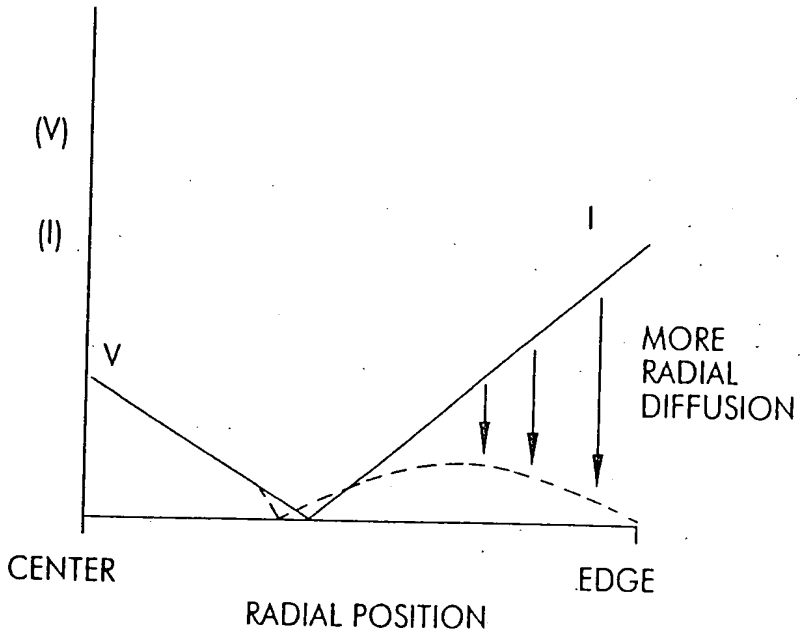

(V)
(I)
I
V
MORE
RADIAL
DIFFUSION
CENTER
EDGE
RADIAL POSITION

FIG.7H

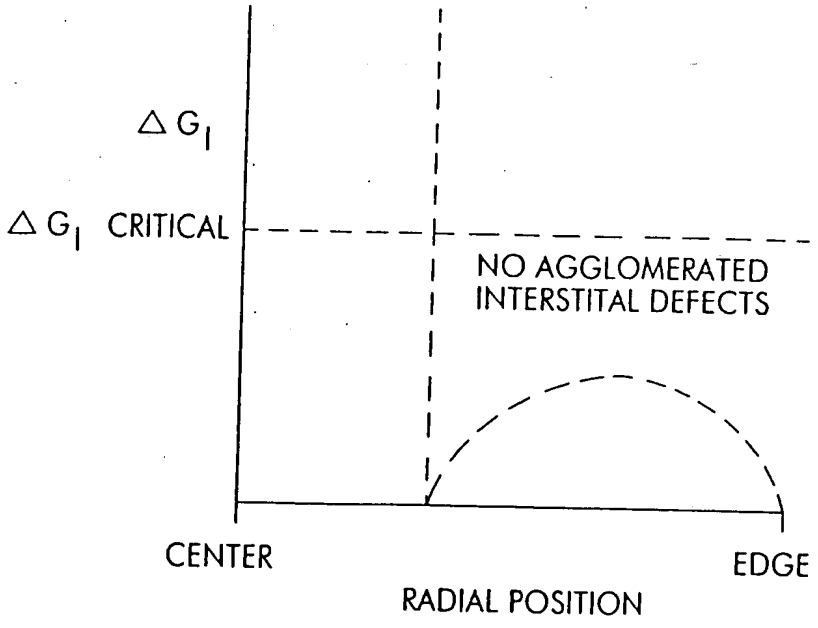

$\triangle G_I$
$\triangle G_I$ CRITICAL
NO AGGLOMERATED
INTERSTITAL DEFECTS
CENTER
EDGE
RADIAL POSITION

FIG.7I

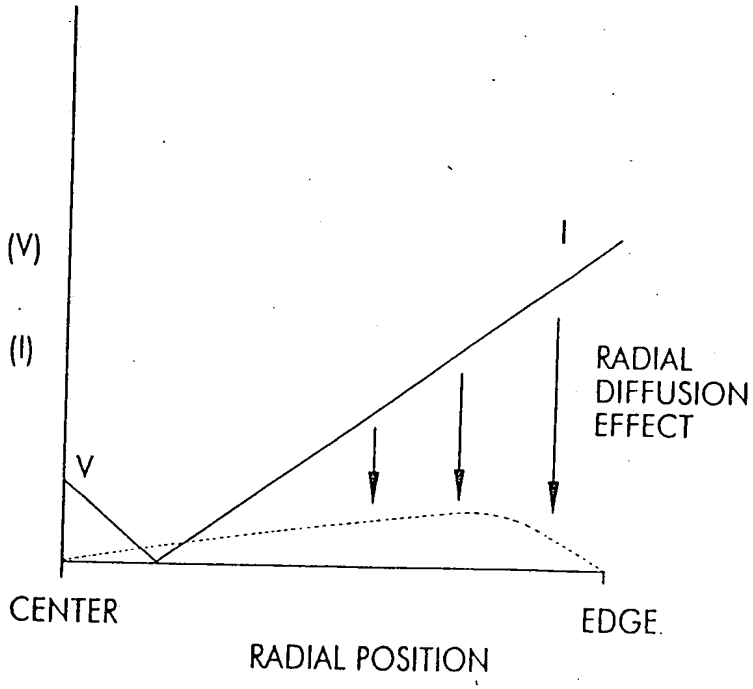

(V)
(I)
I
V
RADIAL
DIFFUSION
EFFECT
CENTER
EDGE
RADIAL POSITION

FIG.7J

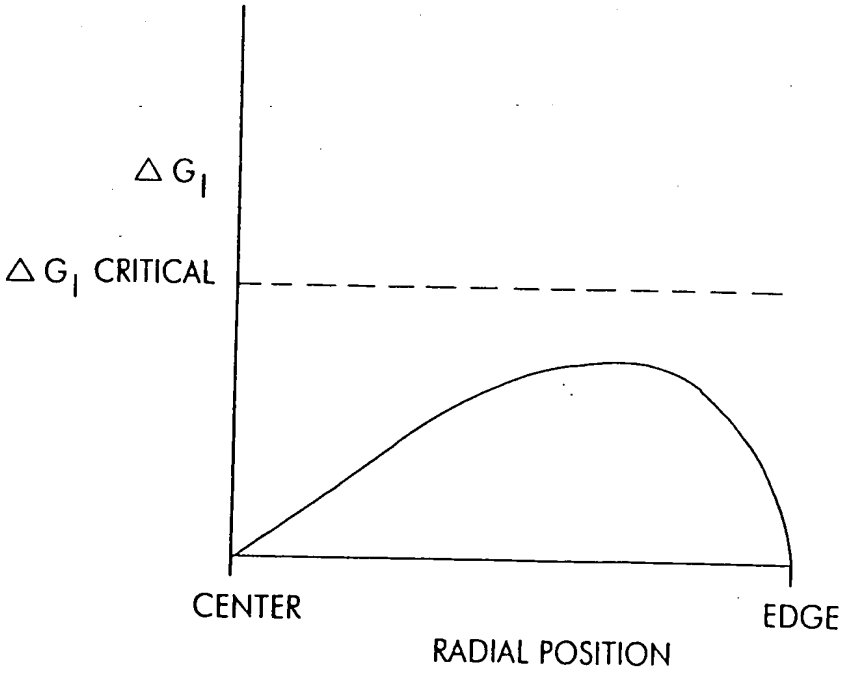

ΔG_I
ΔG_I CRITICAL
CENTER
EDGE
RADIAL POSITION

FIG. 8

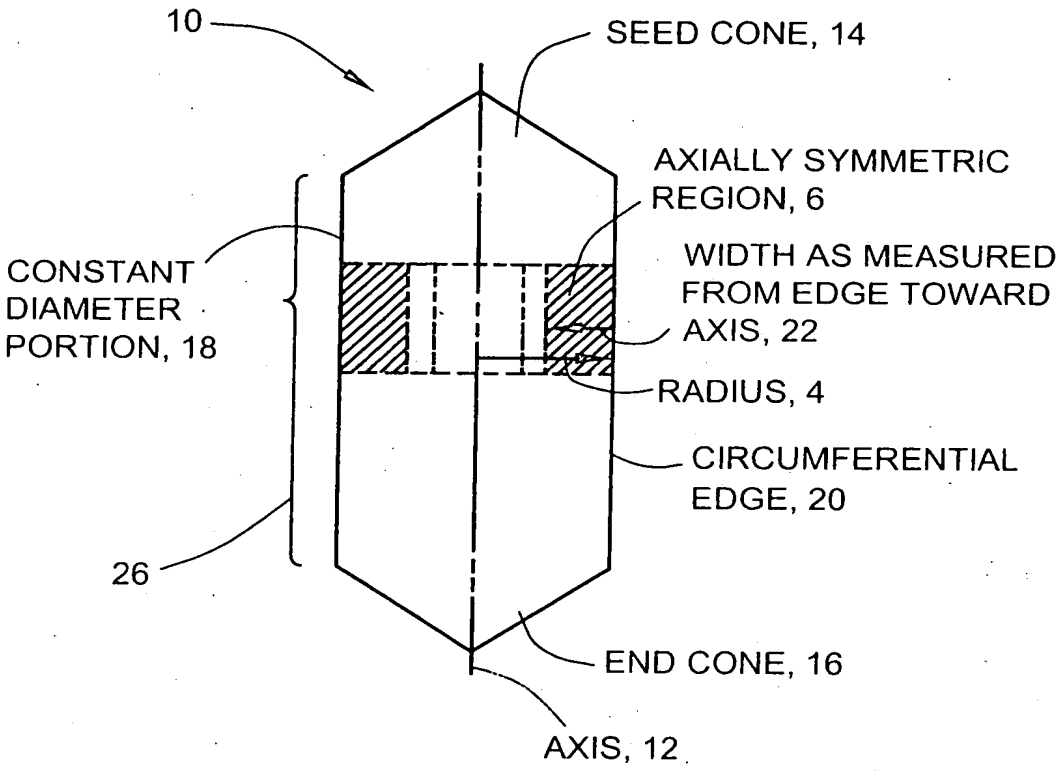

10
SEED CONE, 14
AXIALLY SYMMETRIC REGION, 6
WIDTH AS MEASURED FROM EDGE TOWARD AXIS, 22
CONSTANT DIAMETER PORTION, 18
RADIUS, 4
CIRCUMFERENTIAL EDGE, 20
26
END CONE, 16
AXIS, 12

FIG. 9

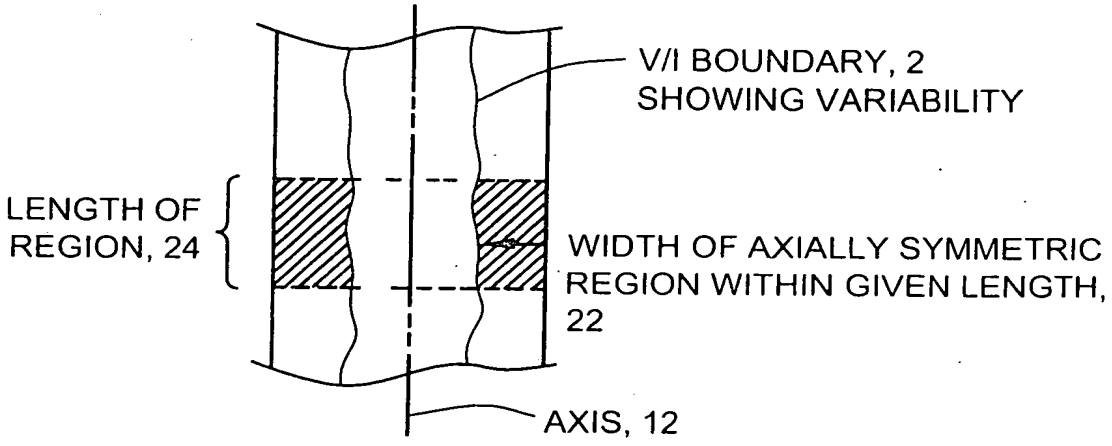

V/I BOUNDARY, 2 SHOWING VARIABILITY
LENGTH OF REGION, 24
WIDTH OF AXIALLY SYMMETRIC REGION WITHIN GIVEN LENGTH, 22
AXIS, 12

FIG.10

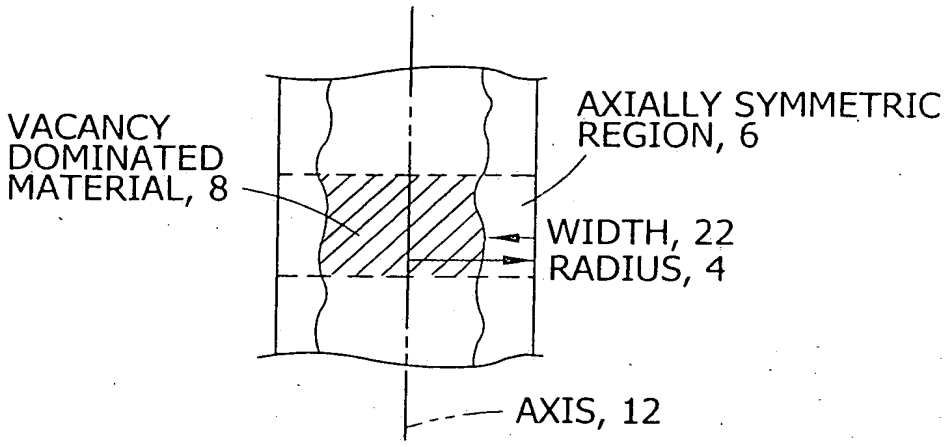


FIG.11

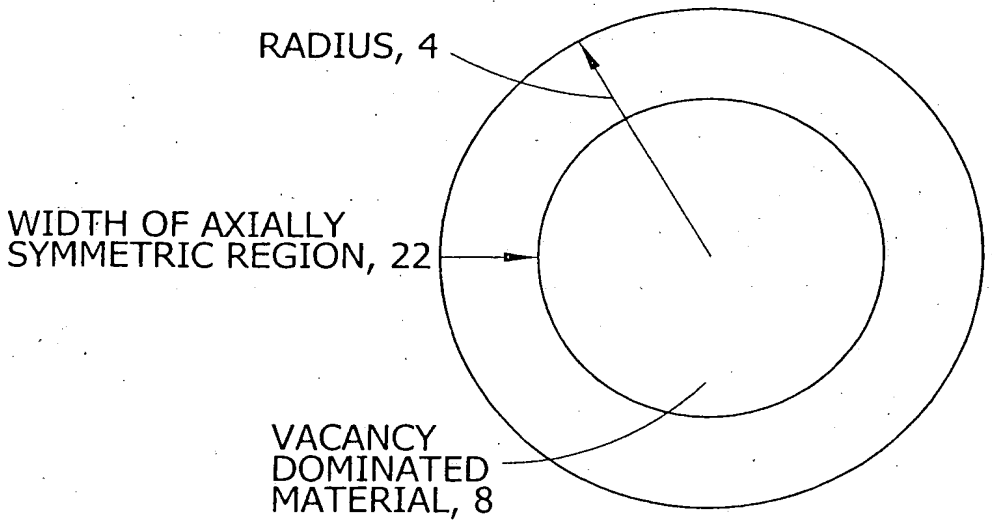


FIG.12

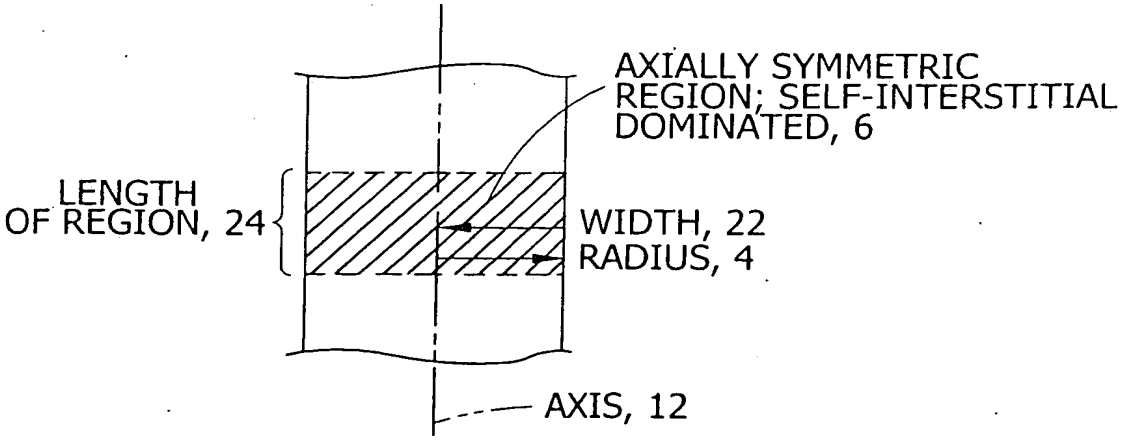


FIG. 13

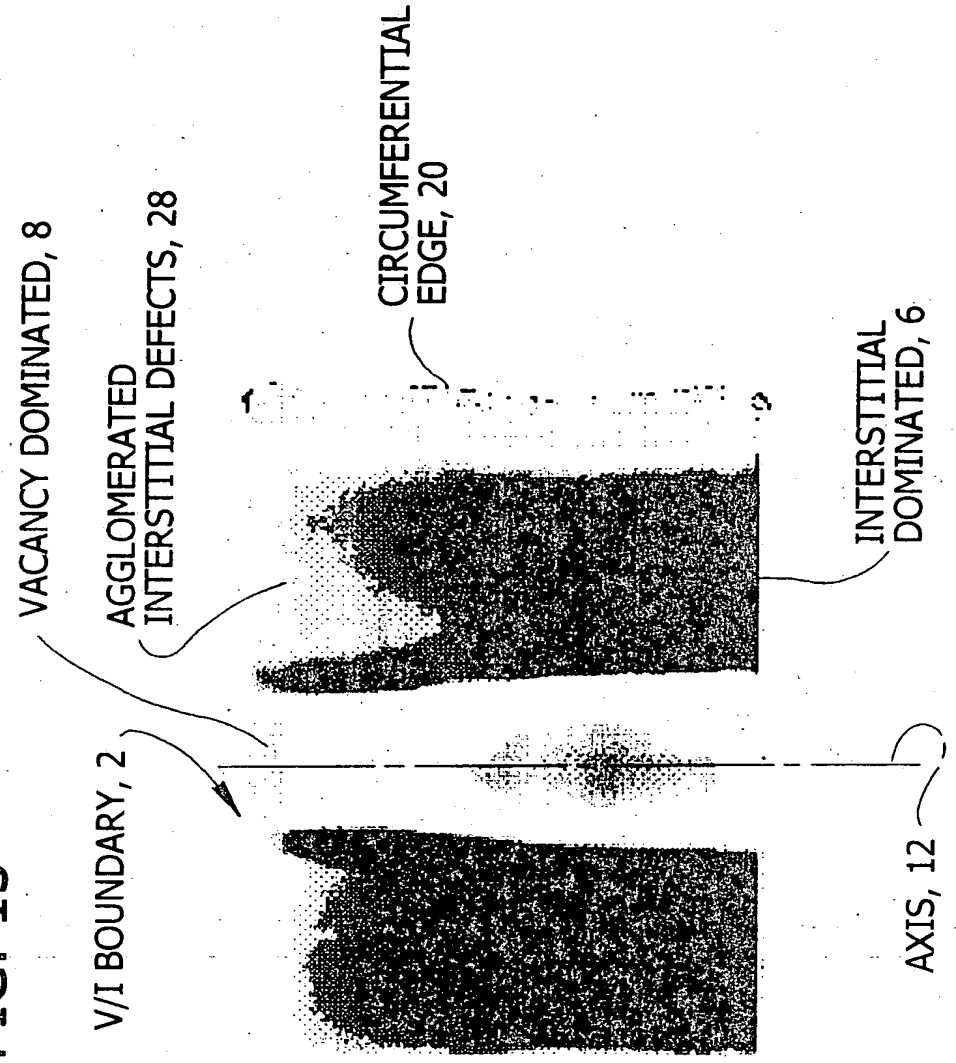

VACANCY DOMINATED, 8
AGGLOMERATED INTERSTITIAL DEFECTS, 28
CIRCUMFERENTIAL EDGE, 20
INTERSTITIAL DOMINATED, 6
V/I BOUNDARY, 2
AXIS, 12

FIG. 14

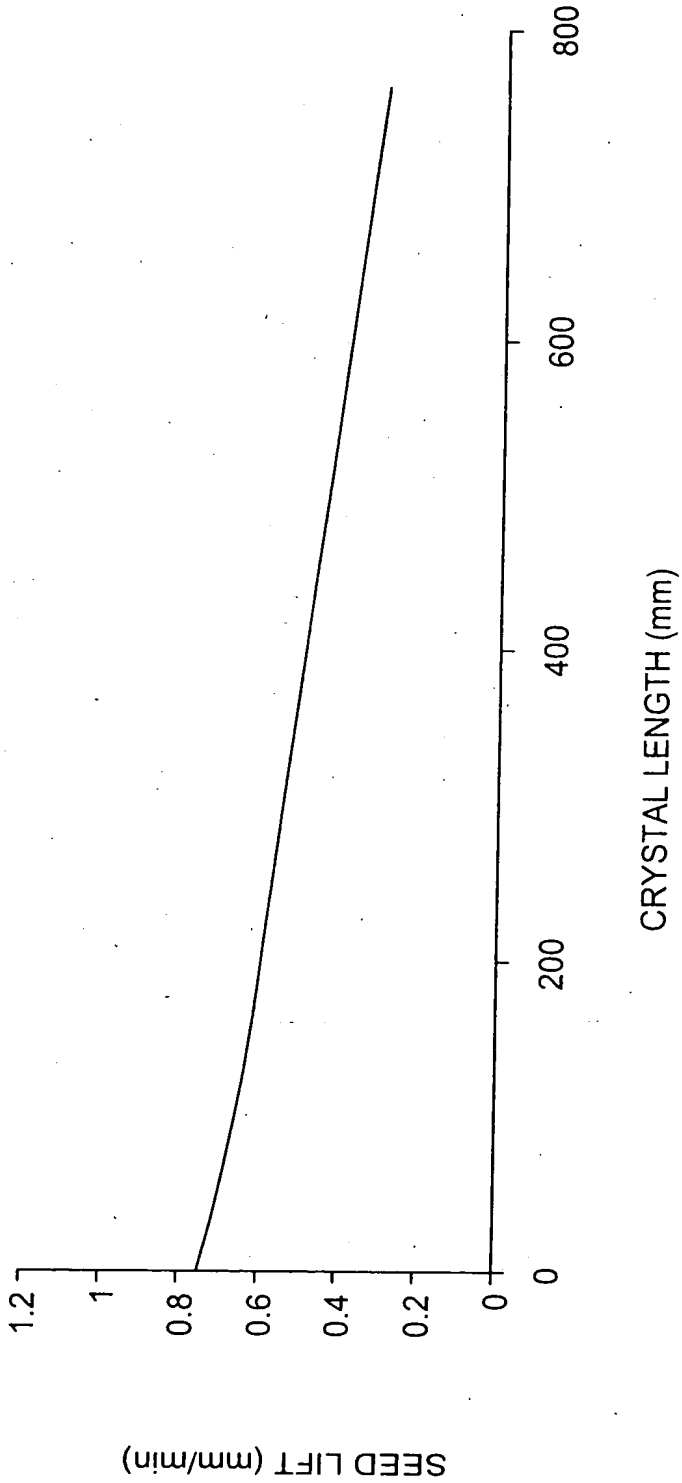

SEED LIFT (mm/min)
1.2
1
0.8
0.6
0.4
0.2
0
0
200
400
600
800
CRYSTAL LENGTH (mm)

FIG. 15

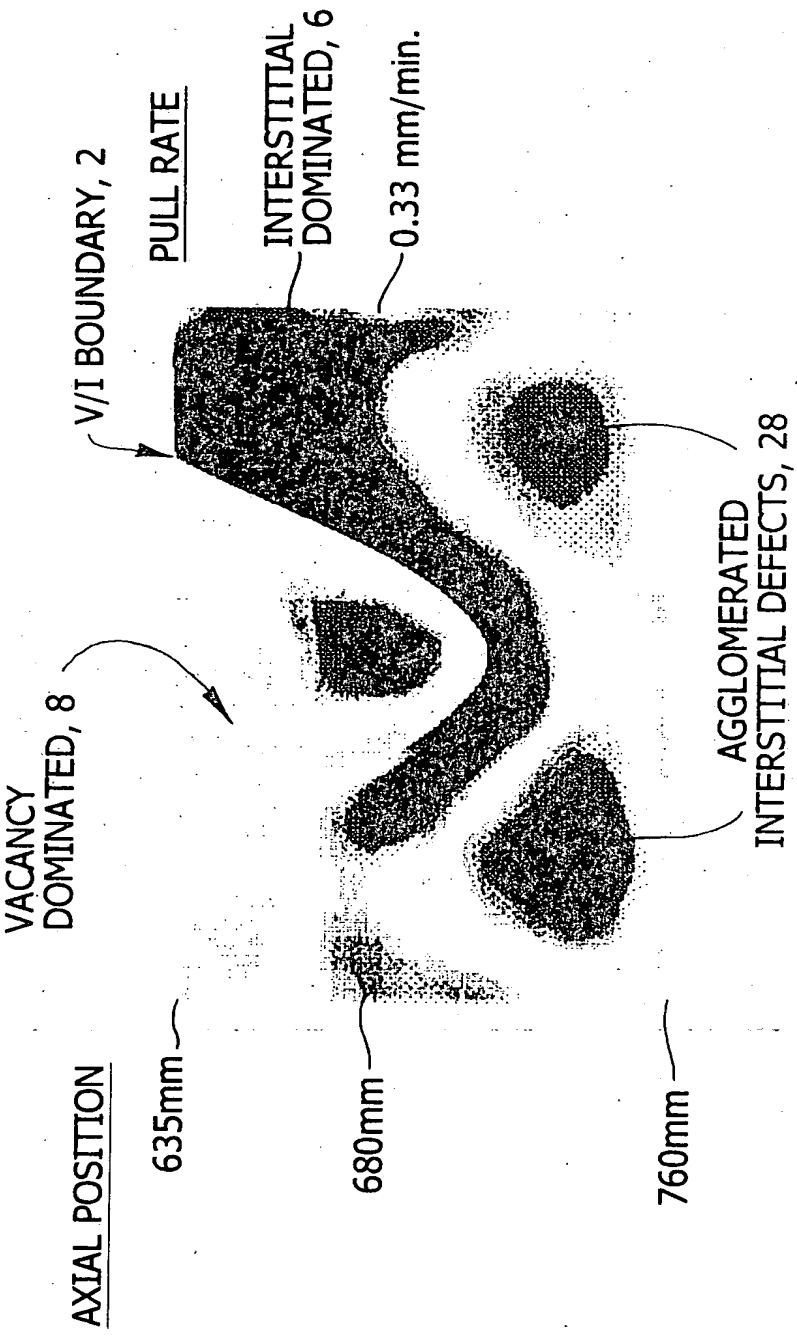

AXIAL POSITION
635mm
680mm
760mm
VACANCY DOMINATED, 8
V/I BOUNDARY, 2
PULL RATE
INTERSTITIAL DOMINATED, 6
0.33 mm/min.
AGGLOMERATED INTERSTITIAL DEFECTS, 28

FIG. 16

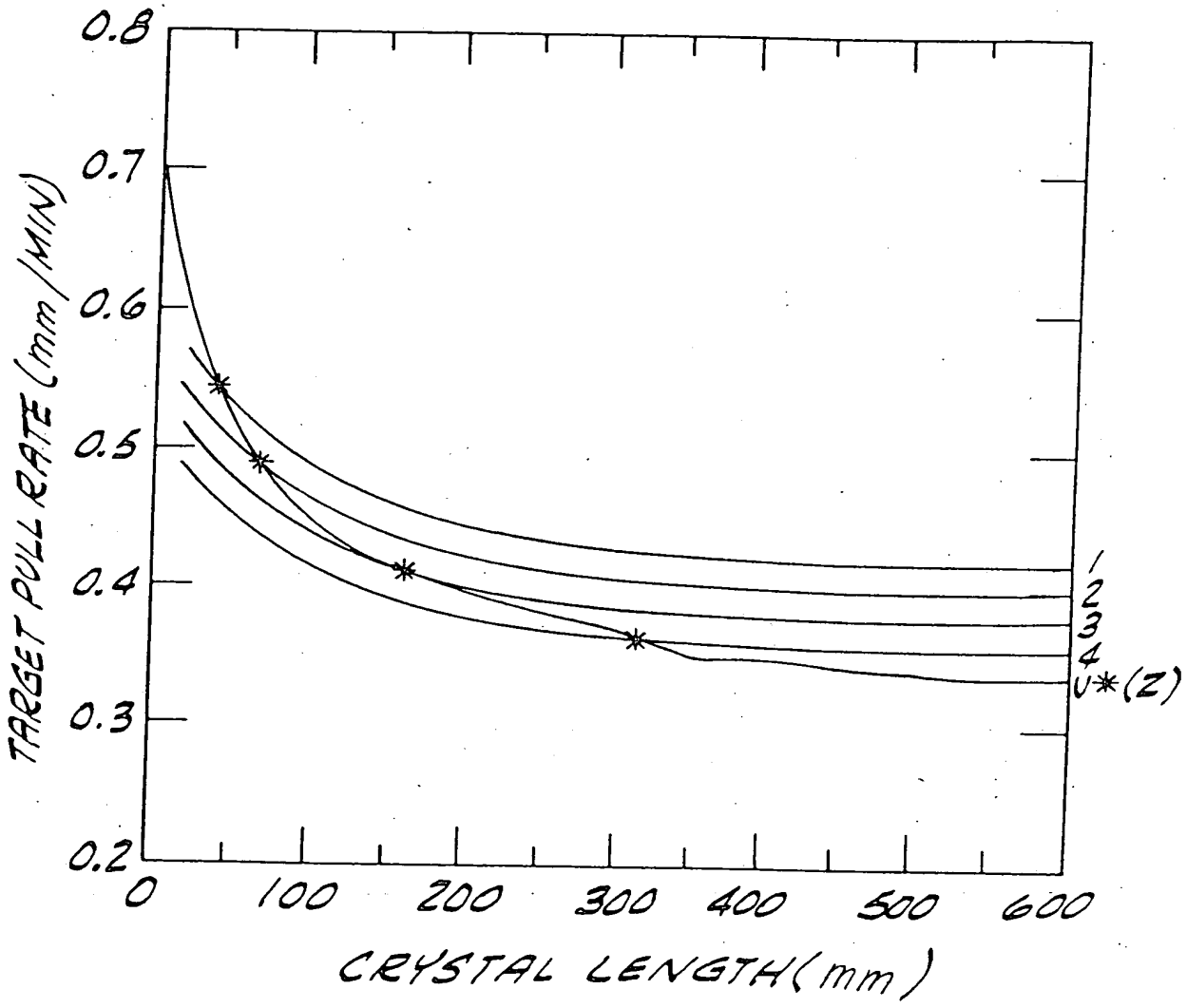

0.8
0.7
0.6
0.5
0.4
0.3
0.2
TARGET PULL RATE (mm/MIN)
0
100
200
300
400
500
600
CRYSTAL LENGTH (mm)
1
2
3
4
V*(Z)

FIG. 17

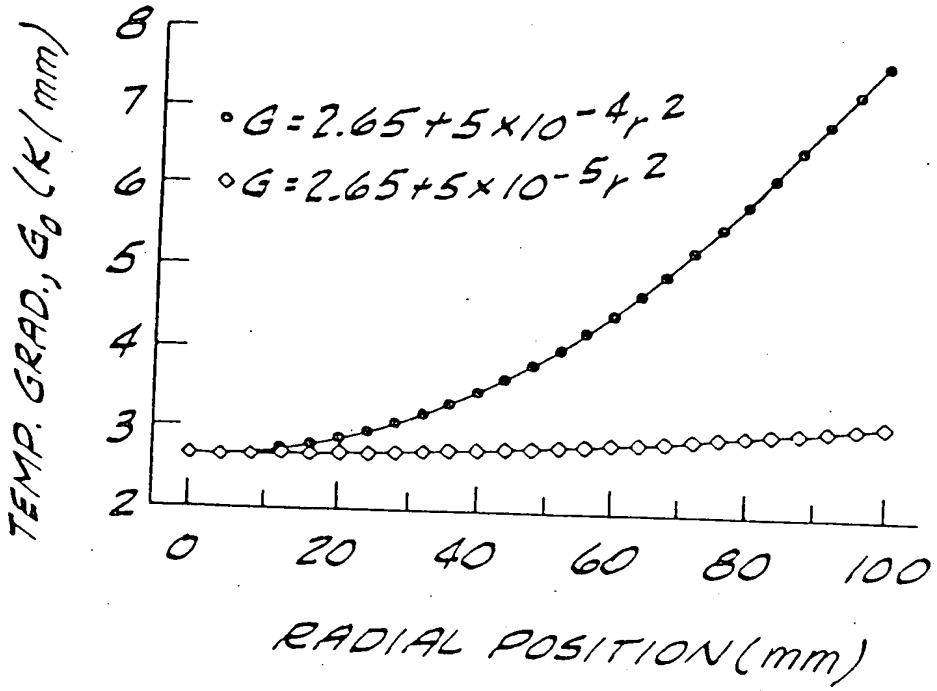

TEMP. GRAD., G_0 (K/mm)
8
7
6
5
4
3
2
$\circ G = 2.65 + 5 \times 10^{-4} r^2$
$\circ G = 2.65 + 5 \times 10^{-5} r^2$
0
20
40
60
80
100
RADIAL POSITION(mm)

FIG. 18

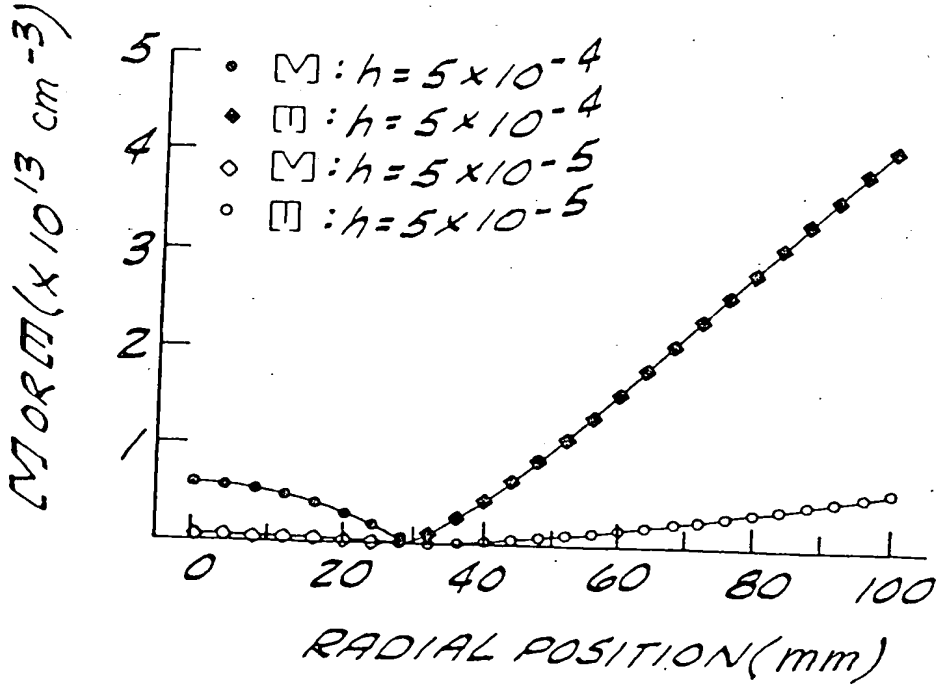

NORM ($\times 10^{13}$ cm^{-3})
5
4
3
2
1
• M : $h = 5 \times 10^{-4}$
◆ E : $h = 5 \times 10^{-4}$
◇ M : $h = 5 \times 10^{-5}$
○ E : $h = 5 \times 10^{-5}$
0
20
40
60
80
100
RADIAL POSITION(mm)

FIG. 19

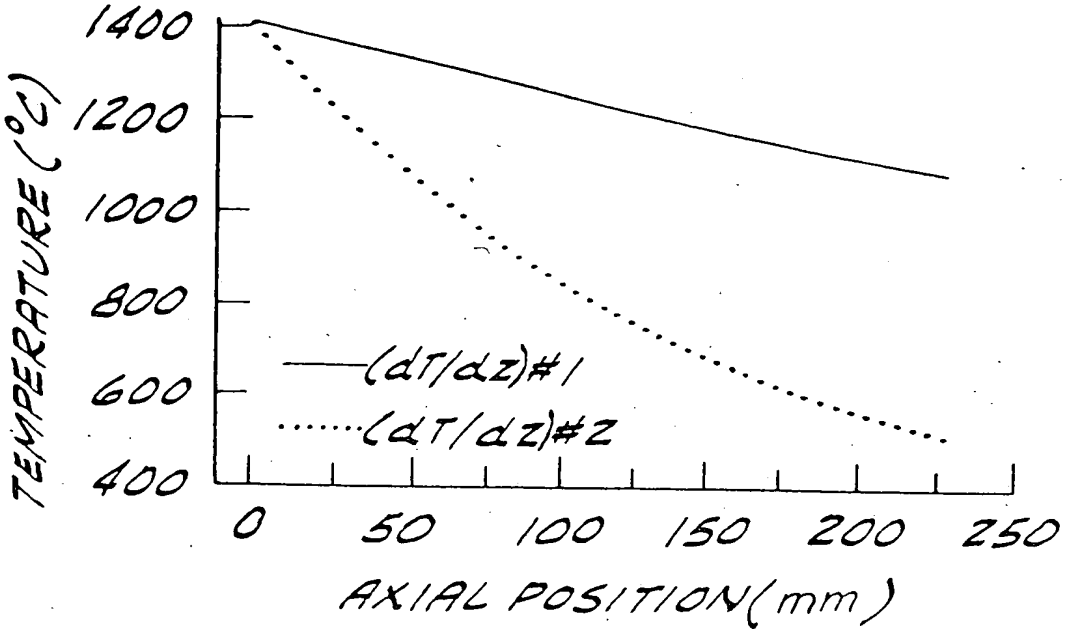

1400
1200
1000
800
600
400
TEMPERATURE (°C)
(dT/dz)#1
(dT/dz)#2
0
50
100
150
200
250
AXIAL POSITION (mm)

FIG. 20

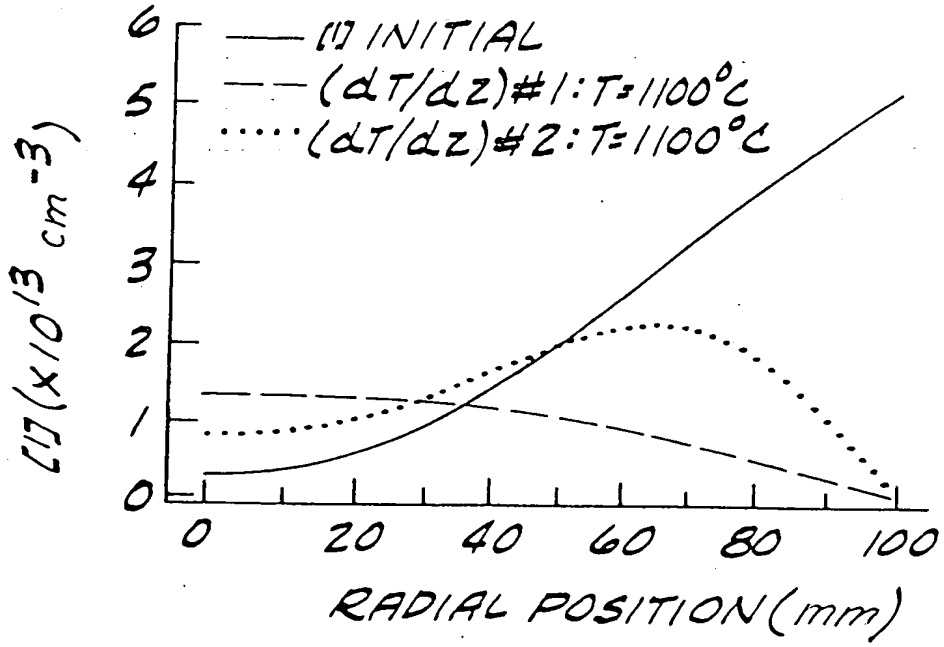

6
5
4
3
2
1
0
[I] (x10^13 cm^-3)
[I] INITIAL
(dT/dz)#1: T=1100°C
(dT/dz)#2: T=1100°C
0
20
40
60
80
100
RADIAL POSITION (mm)

FIG. 21

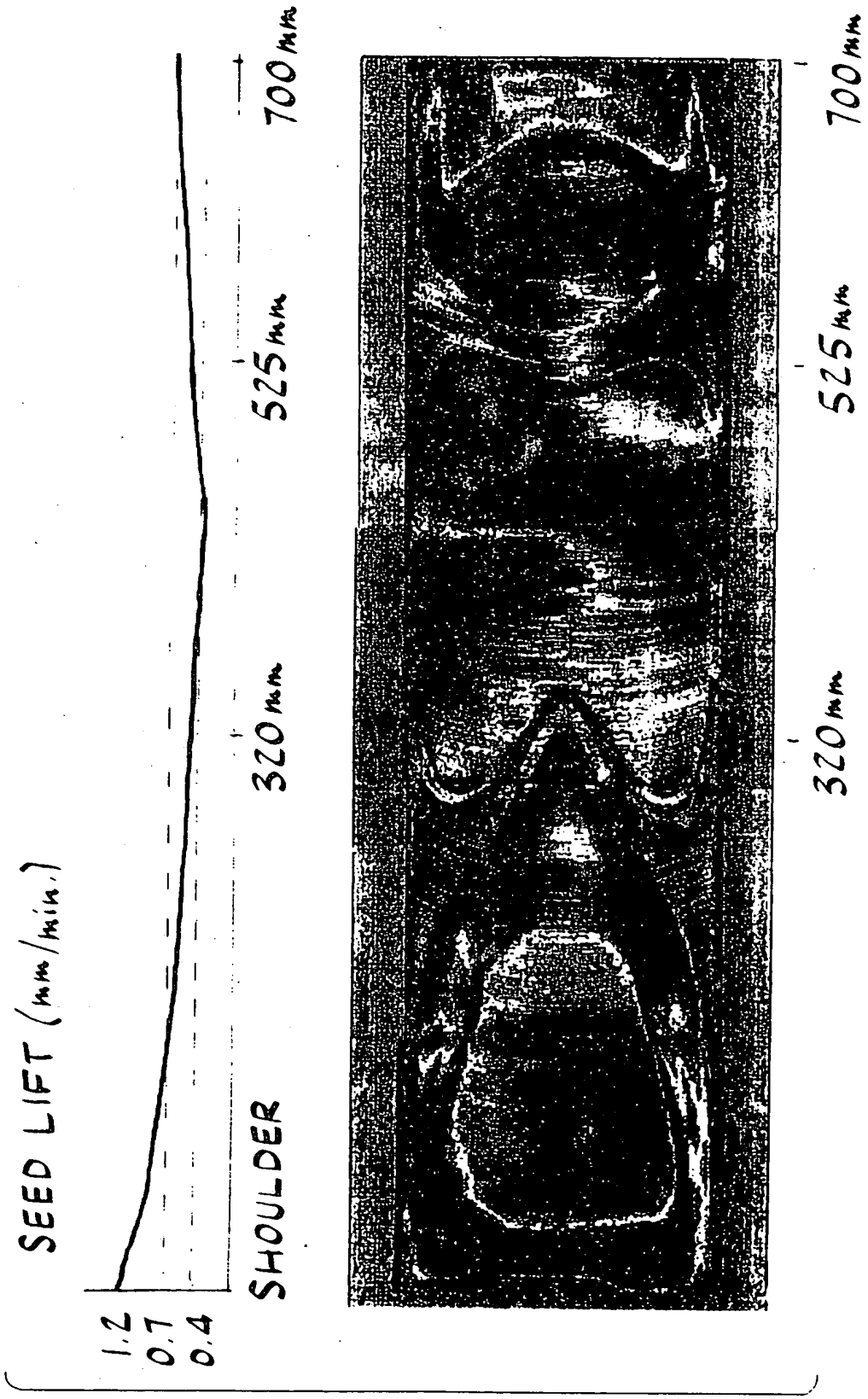

SEED LIFT (mm/min.)
1.2
0.7
0.4
SHOULDER
320 mm
525 mm
700 mm
320 mm
525 mm
700 mm

FIG. 22

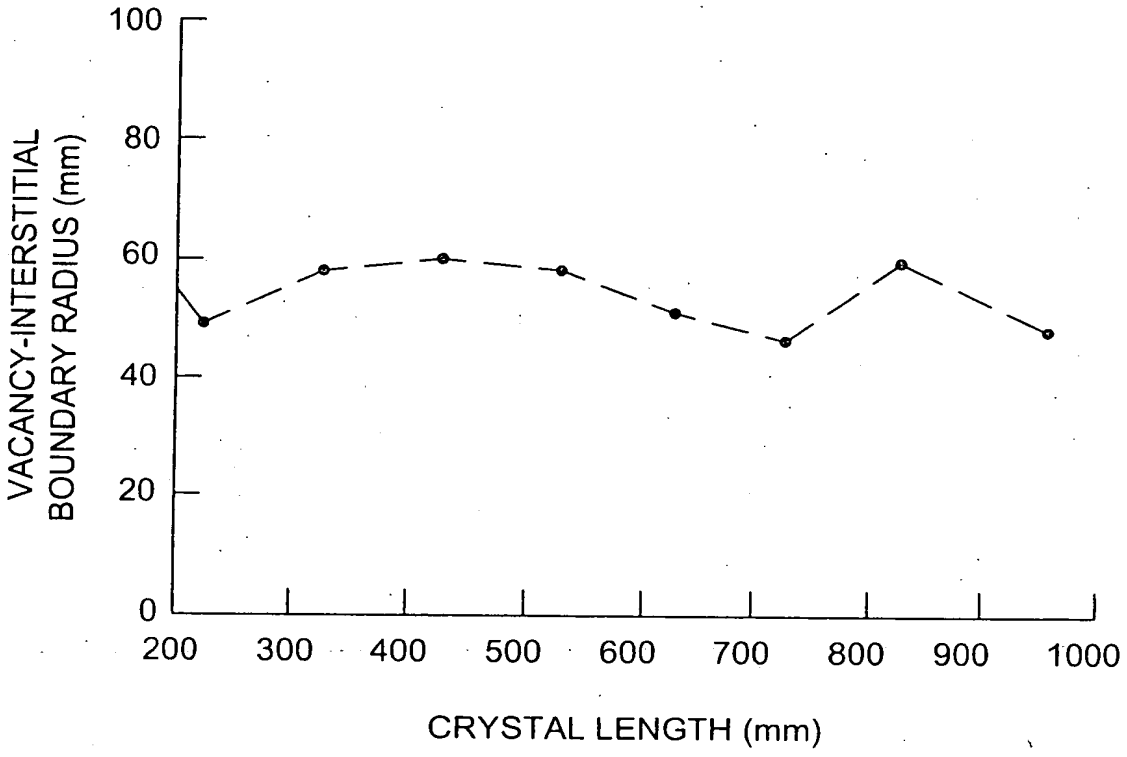

100
80
60
40
20
0
VACANCY-INTERSTITIAL BOUNDARY RADIUS (mm)
200
300
400
500
600
700
800
900
1000
CRYSTAL LENGTH (mm)

FIG. 23A

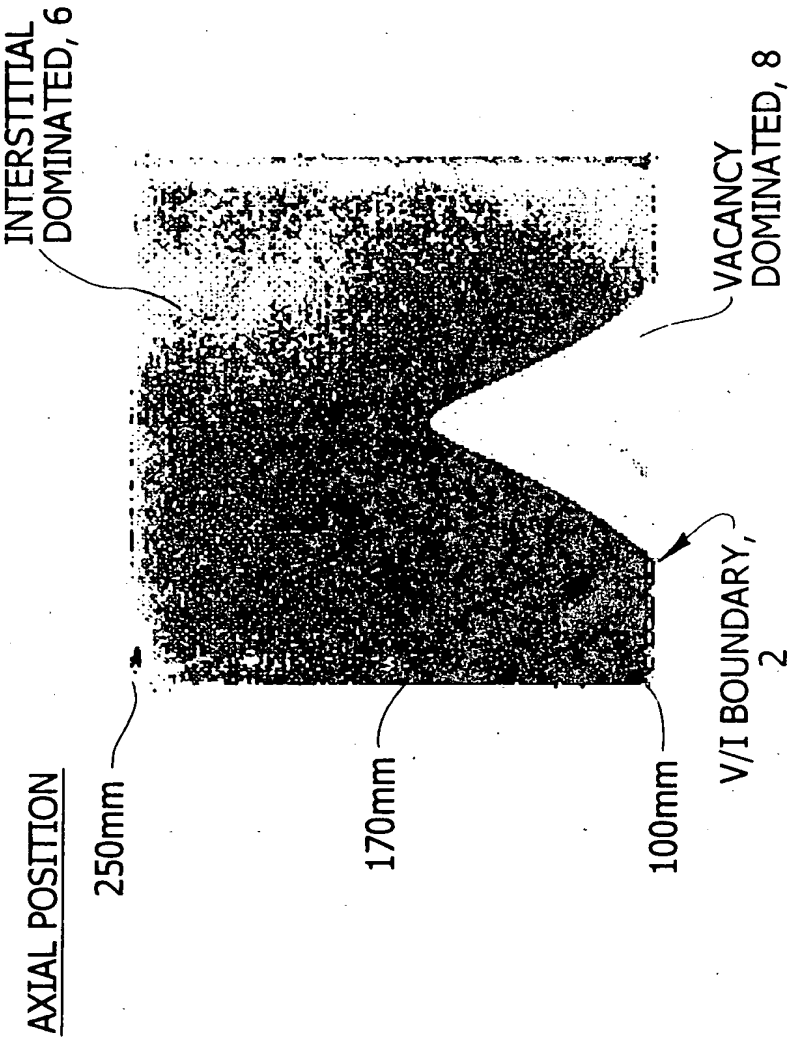

INTERSTITIAL DOMINATED, 6
VACANCY DOMINATED, 8
AXIAL POSITION
250mm
170mm
100mm
V/I BOUNDARY, 2

FIG. 23B

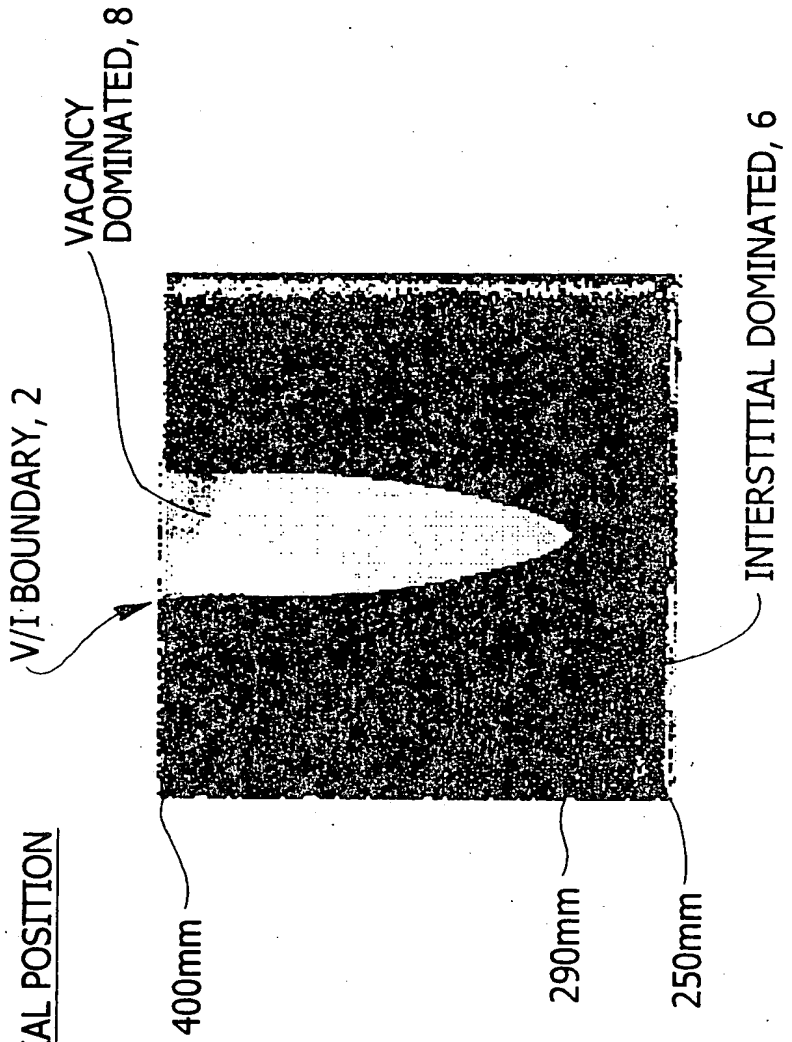

AXIAL POSITION
V/I BOUNDARY, 2
VACANCY DOMINATED, 8
INTERSTITIAL DOMINATED, 6
400mm
290mm
250mm

FIG.24

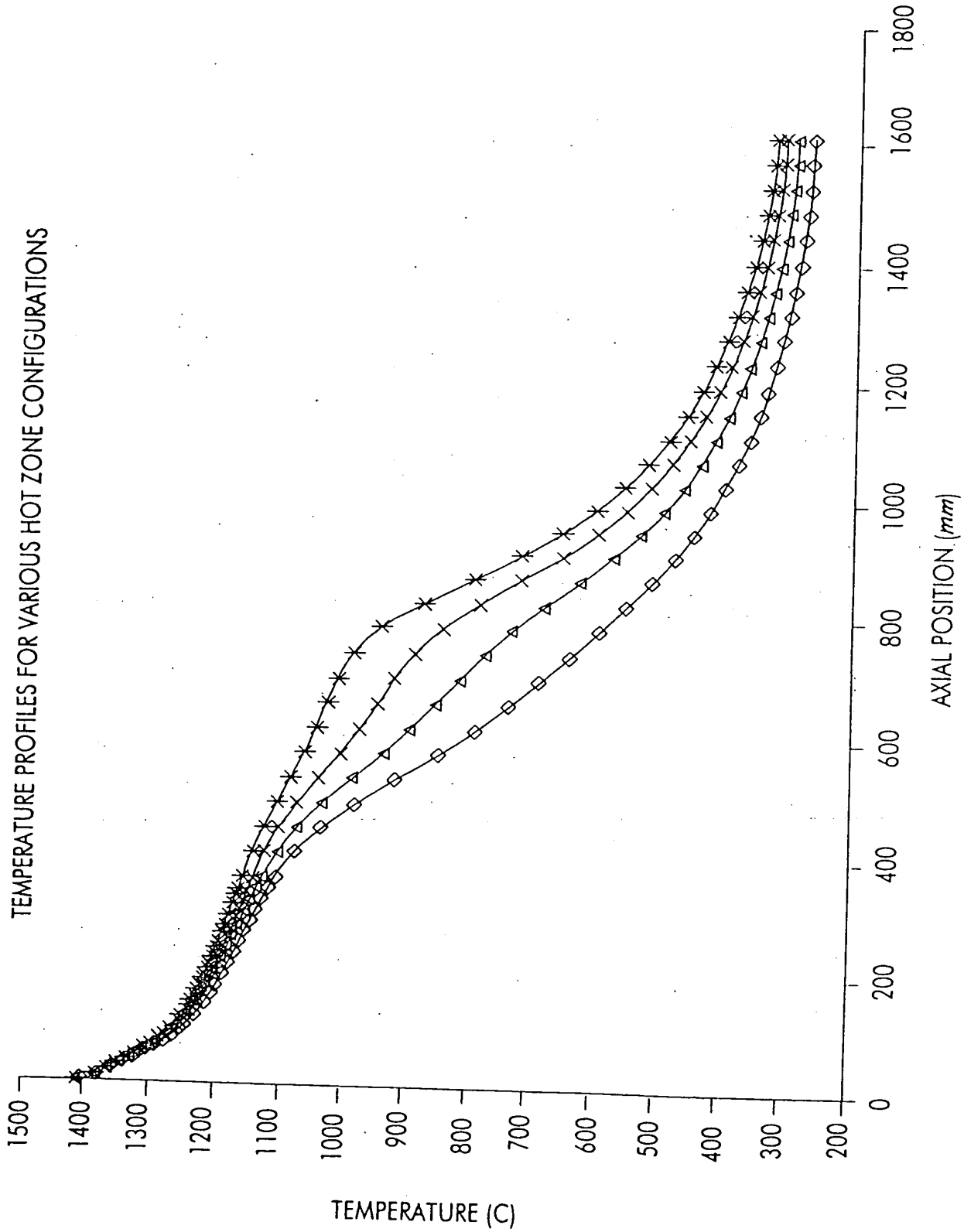

TEMPERATURE PROFILES FOR VARIOUS HOT ZONE CONFIGURATIONS
TEMPERATURE (C)
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
AXIAL POSITION (mm)
0
200
400
600
800
1000
1200
1400
1600
1800

FIG. 25

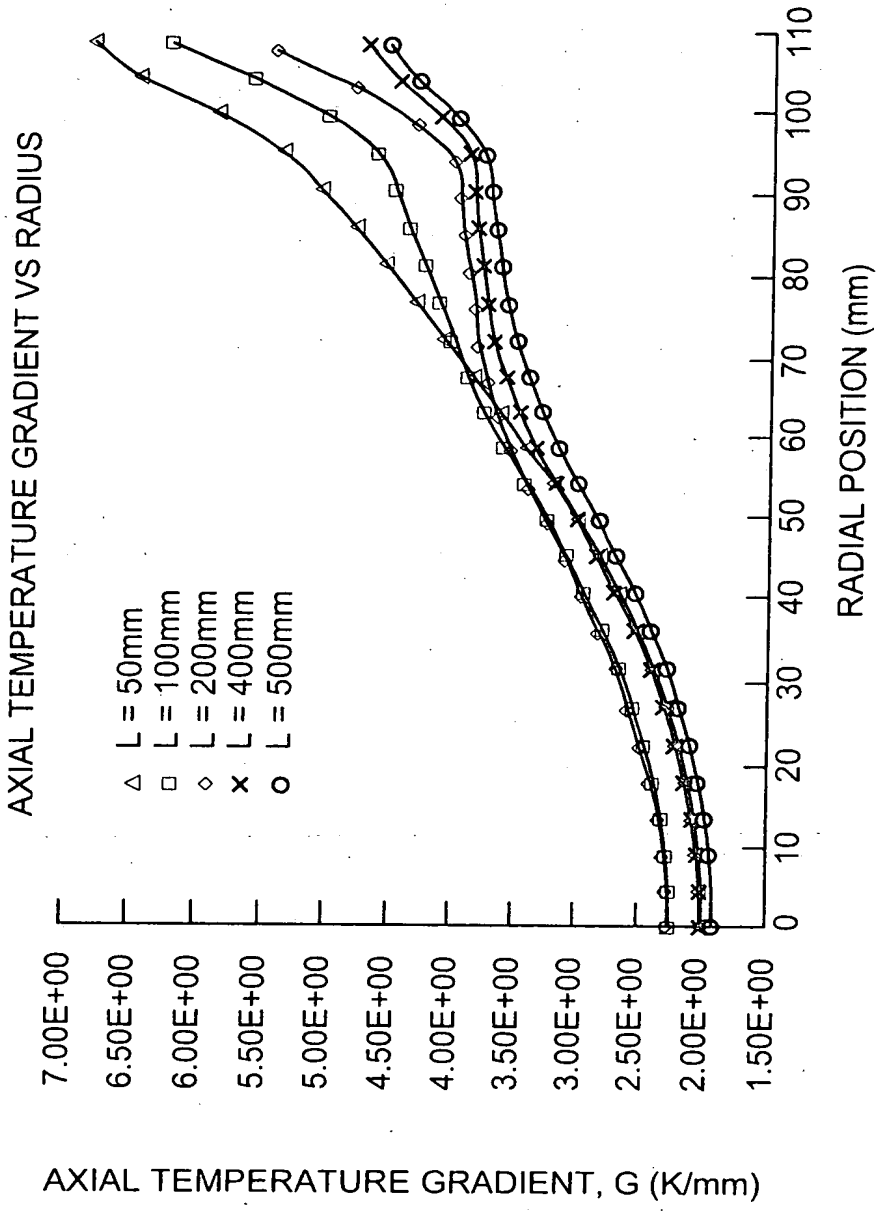

AXIAL TEMPERATURE GRADIENT VS RADIUS
L = 50mm
L = 100mm
L = 200mm
L = 400mm
L = 500mm
7.00E+00
6.50E+00
6.00E+00
5.50E+00
5.00E+00
4.50E+00
4.00E+00
3.50E+00
3.00E+00
2.50E+00
2.00E+00
1.50E+00
0
10
20
30
40
50
60
70
80
90
100
110
RADIAL POSITION (mm)
AXIAL TEMPERATURE GRADIENT, G (K/mm)

FIG.26

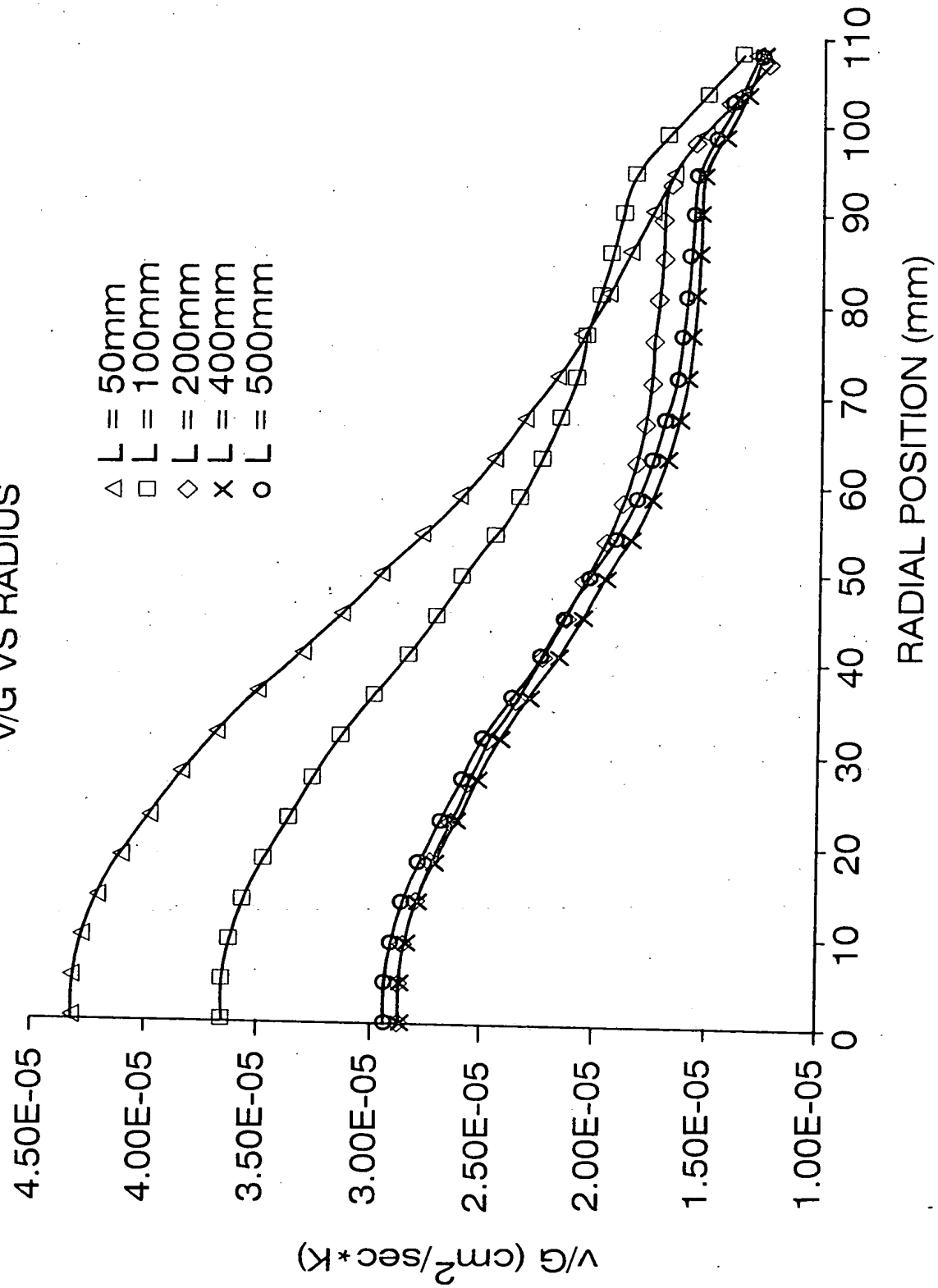

v/G VS RADIUS
L = 50mm
L = 100mm
L = 200mm
L = 400mm
L = 500mm
v/G (cm²/sec*K)
4.50E-05
4.00E-05
3.50E-05
3.00E-05
2.50E-05
2.00E-05
1.50E-05
1.00E-05
0
10
20
30
40
50
60
70
80
90
100
110
RADIAL POSITION (mm)

FIG. 27

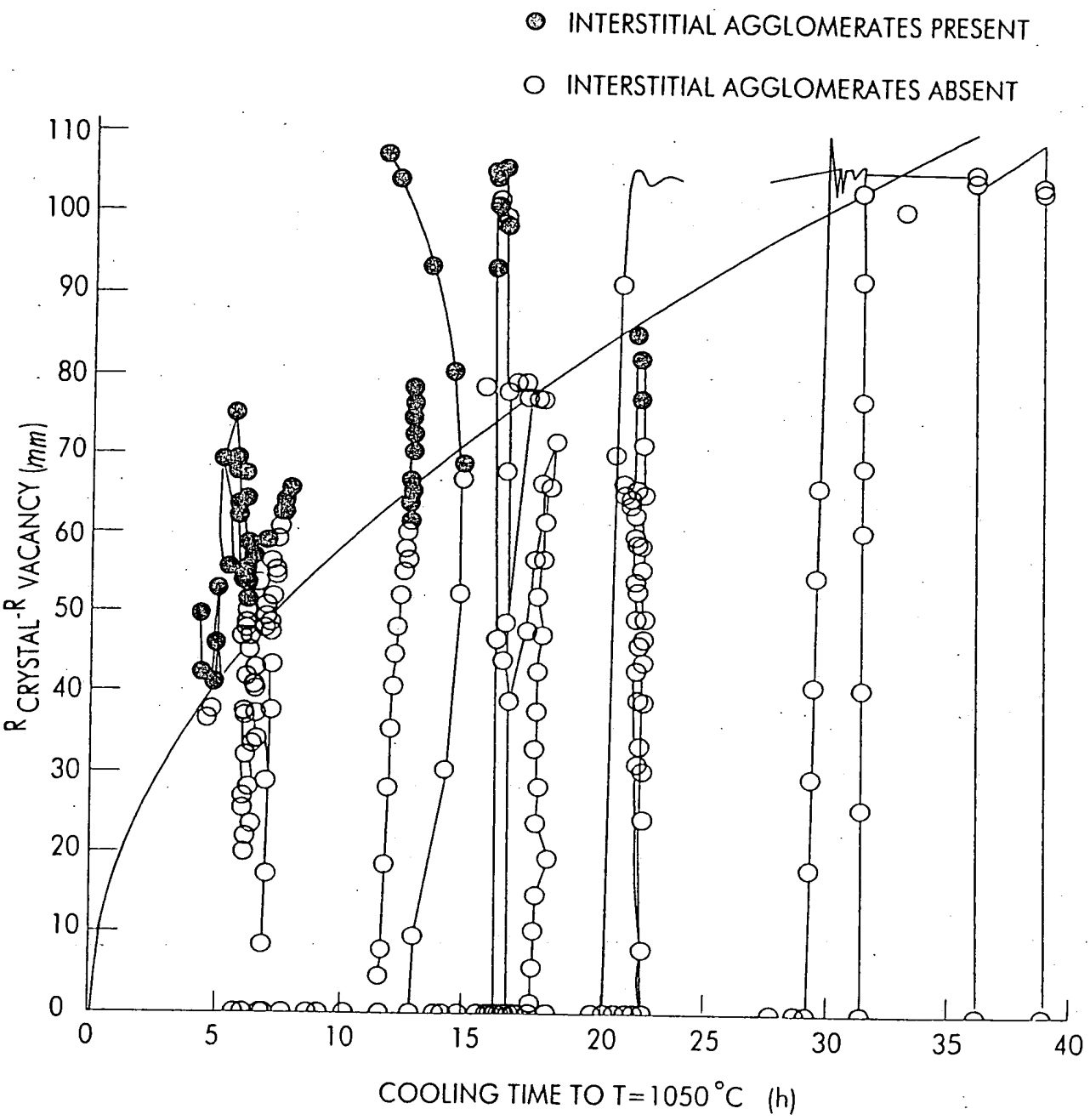

INTERSTITIAL AGGLOMERATES PRESENT
INTERSTITIAL AGGLOMERATES ABSENT
$R_{CRYSTAL}$-$R_{VACANCY}$ (mm)
110
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
COOLING TIME TO T=1050 °C (h)

FIG. 28

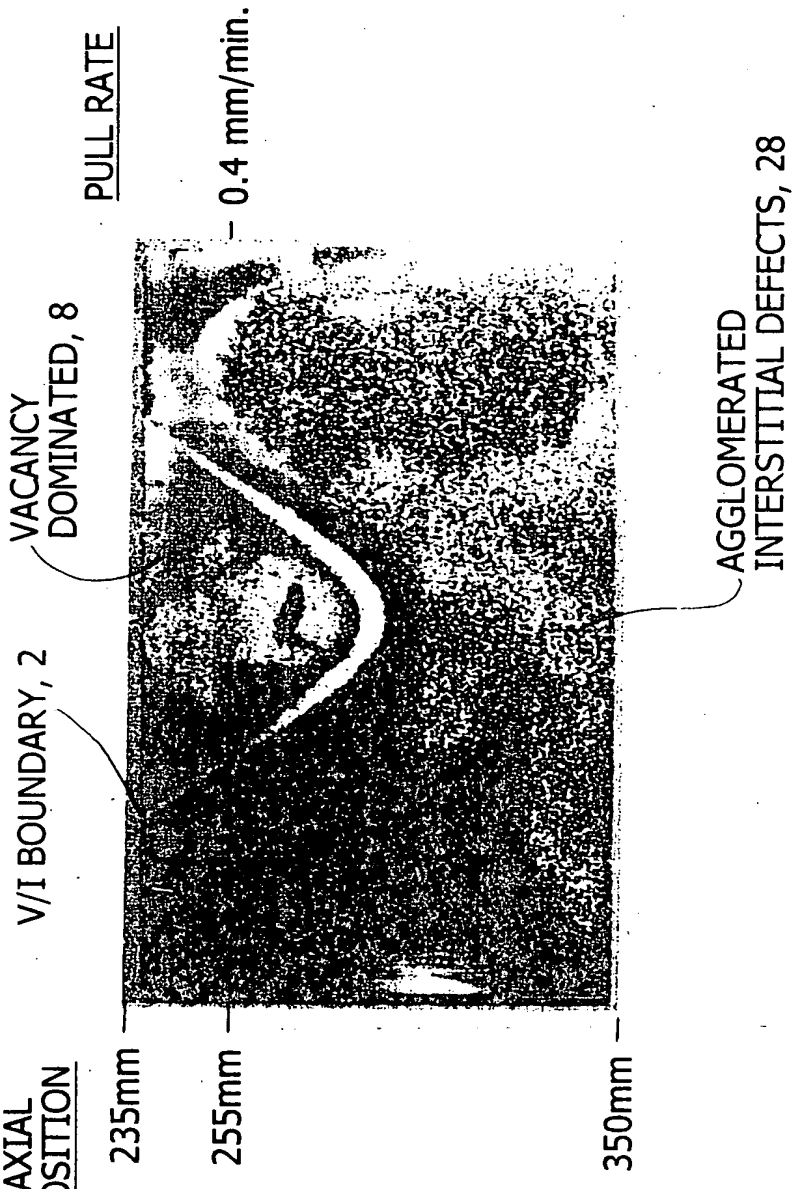

AXIAL POSITION
235mm
255mm
350mm
V/I BOUNDARY, 2
VACANCY DOMINATED, 8
PULL RATE
0.4 mm/min.
AGGLOMERATED INTERSTITIAL DEFECTS, 28

FIG. 29

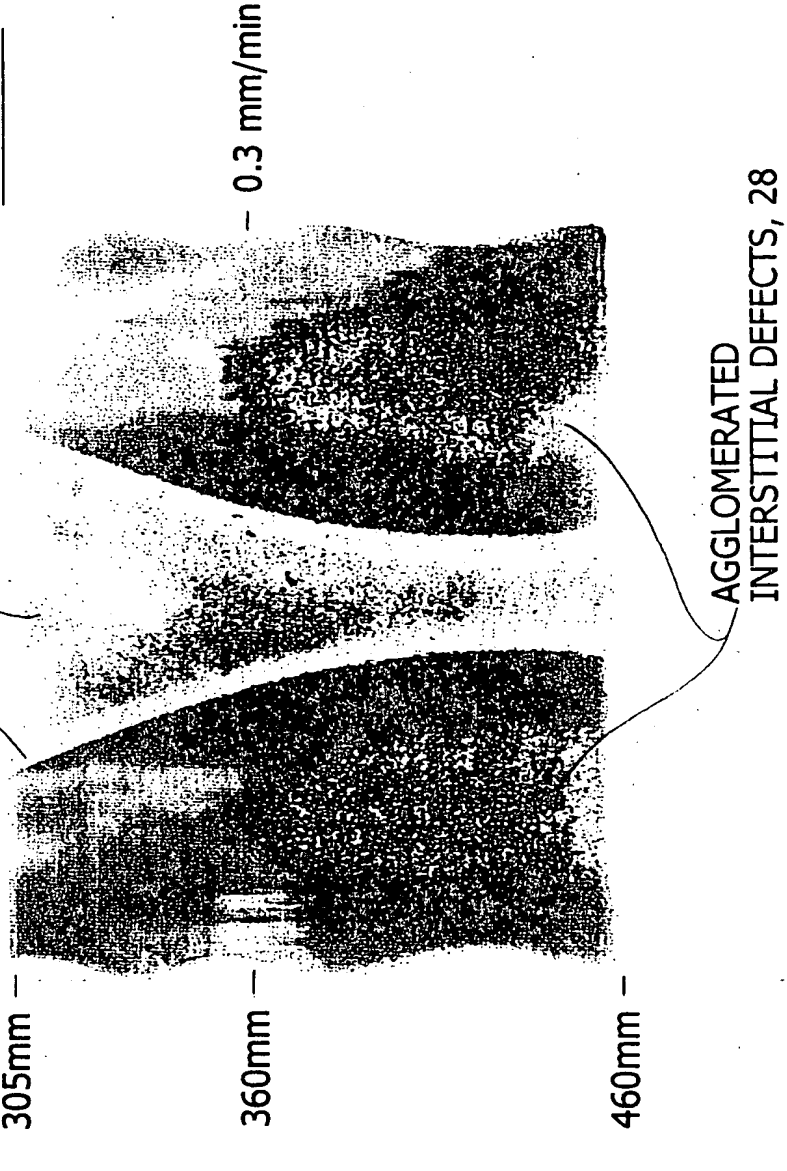

PULL RATE
0.3 mm/min.
AXIAL POSITION
305mm
360mm
460mm
V/I BOUNDARY, 2
VACANCY DOMINATED, 8
AGGLOMERATED INTERSTITIAL DEFECTS, 28

FIG. 30

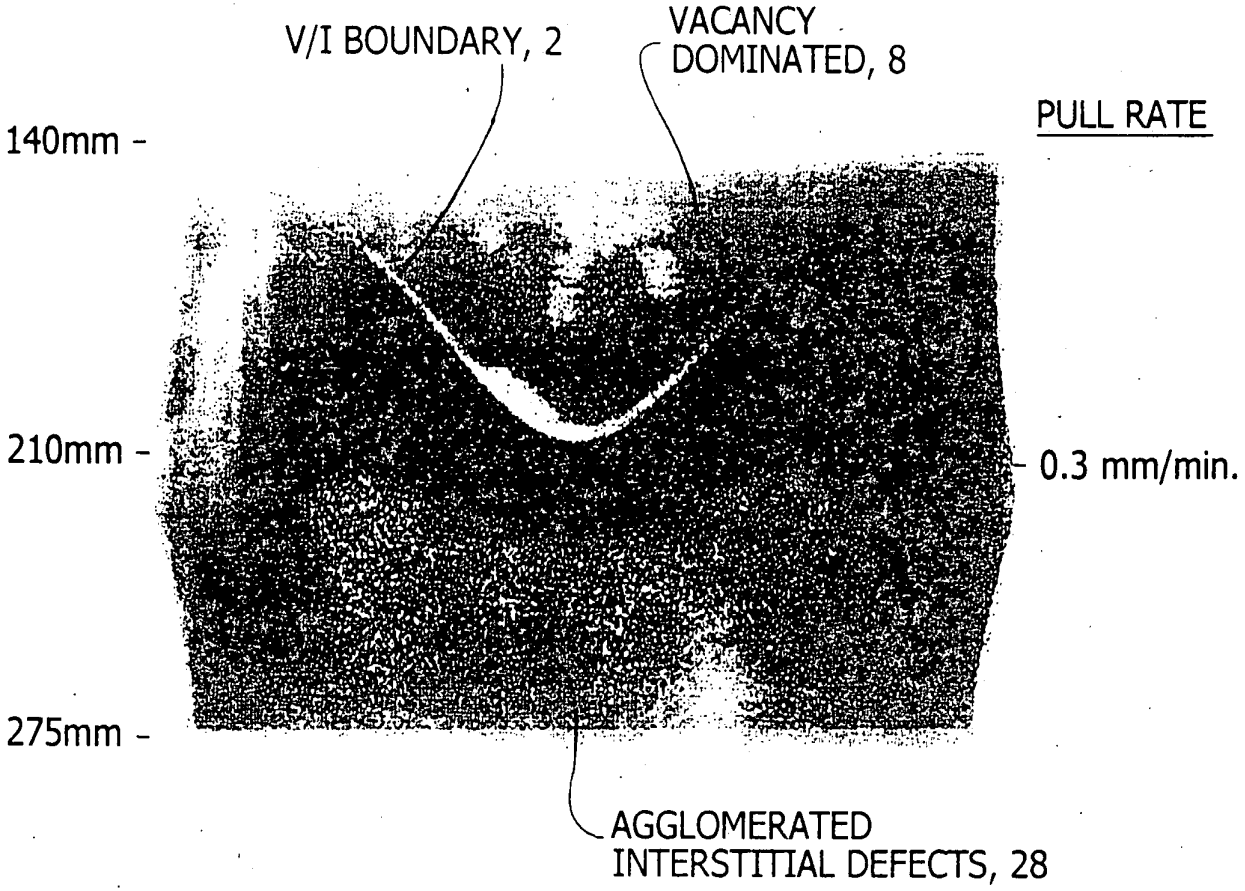
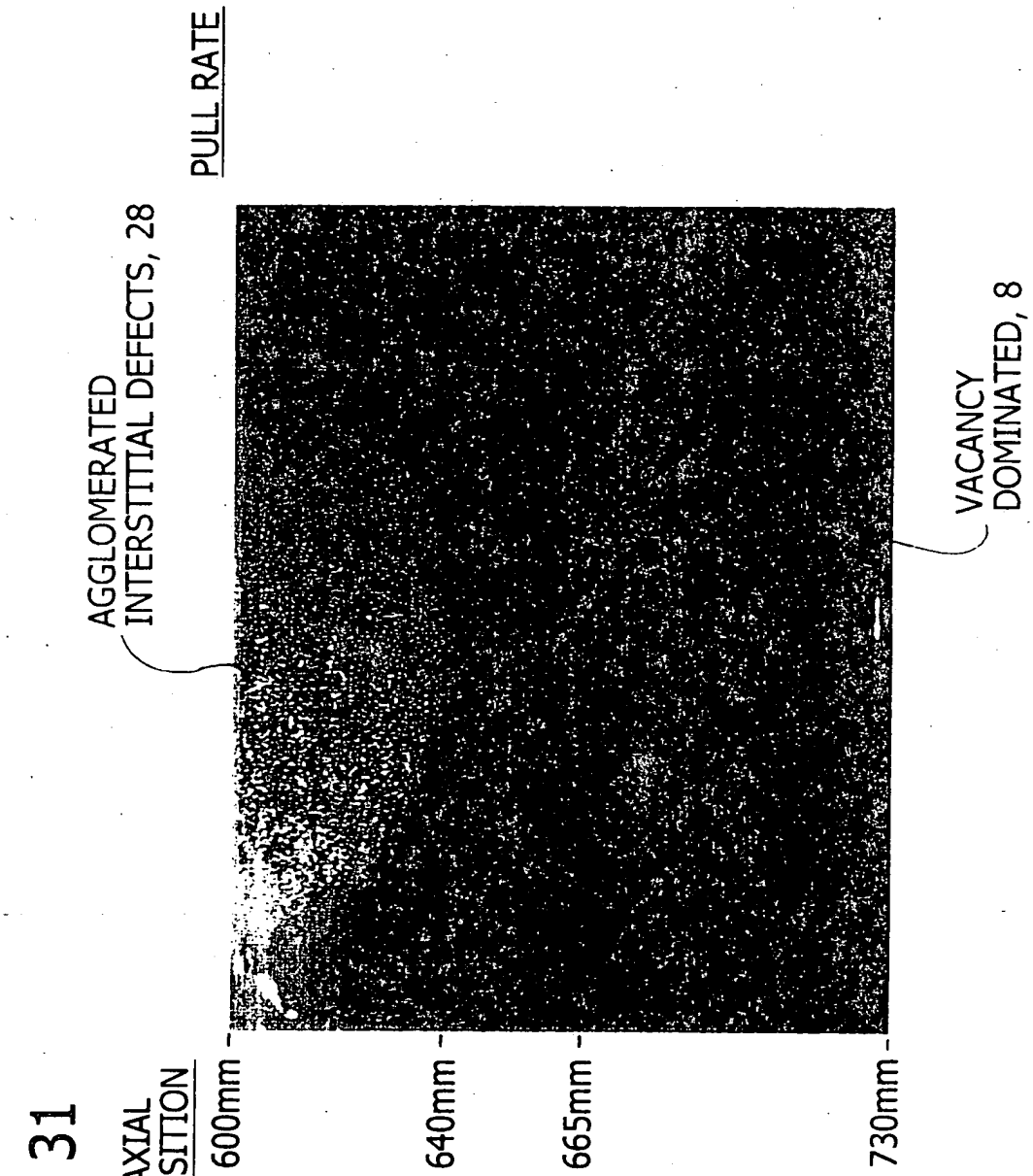

V/I BOUNDARY, 2
VACANCY DOMINATED, 8
PULL RATE
140mm -
210mm -
275mm -
0.3 mm/min.
AGGLOMERATED INTERSTITIAL DEFECTS, 28

FIG. 31


PULL RATE
AXIAL POSITION
600mm
640mm
665mm
730mm
AGGLOMERATED INTERSTITIAL DEFECTS, 28
VACANCY DOMINATED, 8